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DIVERSION OF CANALS

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IRRIGATION AND DRAINAGE
DIVISION

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DIVERSION OF CANALS

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SYNOPSIS

The design of a proper diversion between branch and main canals helps in controlling the distribution of sediment between them. The present work is a first step in studying the flow conditions around the diversion.

A model was tested to find the effect of the shape of both canals and the ratio of flow in them, on the velocity distribution in the branching region. The induced secondary currents were studied for different cases. The separation zones produced at the diversion were traced by dye and verified by a current meter.

It is found that the main factor affecting the problem is the ratio between the mean velocities in the main and branch canals. A relatively high velocity in the main canal requires bigger curvature at the diversion point in order to avoid separation. The relation between the ratio of velocities and the radius of curvature is given in Fig. 15. The secondary currents are represented by the spiral strength in the branch canal. They are greatly increased with the velocity ratio causing a high amount of sediment to enter the branch. The relation between spiral strength and the velocity ratio is given in Fig. 14. High relative velocity in the branch is recommended to reduce separation and secondary currents, and thus reducing the amount of the branch sediment.

INTRODUCTION

Many years ago it was observed that the water at most of canal junctions could not carry sediment in direct proportion to their flow. It usually happened that the major part of the sediment coming through the main canal would be forced towards one of its small branches. As the sediment carrying capacity of such a branch would not be enough to handle that quantity, sediment would deposit causing the reduction of the effective section of that branch.

The present work had been carried out with the object of studying the different factors which would affect the distribution of both water and sediment on different branches diverting from a main canal. With a proper design of the intake of a branch, control of water and sediment could be improved.

This problem includes so many variables that its study must be divided into different parts. Each part will cover few of these variables. Many results reached by previous investigators did not agree because the variables were not clearly defined and separated.

The variables can be divided into three groups:

1) Those related to the shape of the canal:
   a) The straightness or curvature of both the main and the branch canals. This can be represented by the radius of curvature of the canal divided by its width r/b.

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b) Relative width of branch, bb, to that of main canal bm, represented by the ratio bb/bm.

c) Angle of twist between the two canals.

Other factors such as change of bed levels or side slopes may affect the problem.

2) Those related to the dynamics of the water flow. They can be represented by Reynolds Number, Rn, Frond's Number, F, and the ratio between the mean velocity in the main canal to the mean velocity in the branch V_m/Vb.

3) Those related to the transported sediment, both in suspension and as bed load. These were studied by Hunter Rouse (1)[2] and can be represented by the concentration at bed Co, sand diameter representing the absolute roughness divided by the depth of water e/d, mean velocity of flow to the mean settling or fall velocity of the sediment, V/W_m, the geometric standard deviation of the settling velocity from its mean σ_w which represent the size distribution of the sediment, and $\frac{W_m t}{a}$ where t is the duration of the test and a is certain length representing the field of the test.

The total amount of sediment, G, entering the branch will be a function of all the previous variables.

$$G = \phi \left(r/b,\ bb/bm,\ \theta,\ Rn,\ F,\ \frac{Vb}{V_m},\ Co,\ \frac{e}{d},\ \frac{V}{W_m},\ \sigma_w,\ \frac{Wmt}{a}\right)$$

Each of these variables must be studied separately in the sequence of independence, e.g., the relation between the shape and the water dynamics must be studied before introducing the sediment problem. A survey of the work previously done in this field will be of great help in order to proceed without duplication.

The work on the bend will be discussed also, because the diversion of water is really accomplished by deflecting certain amount of water away from its original direction and hence the problem is similar to that of flow around a bend.

For an ideal flow the diversion problem can be solved by superposing a direct flow and a flow around a bend.

Previous Work

Although many engineers have discussed this problem, very few experiments have been done in laboratory.

Most of the work done by engineers was based on their field observations. Despite the many variables included they aim to hit the solution from one shot. Some trials were made by studying models using water loaded with any sediment available. The results of such a study must be handled with great care. It may give an idea about certain phenomena at certain specific condition, but it is completely erroneous to generalize such results. The results of one of such trials were given in Freeman (2) for the effect of diversion angle (Fig. 1). The channels were of rectangular sections with sharp edges at points of branching and layed on small slopes. These curves show the high tendency of sediment to enter the branch, but the values of the given percentages can not be extrapolated to cover any different conditions.

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2. Numerals in parantheses, thus (1), refer to corresponding numbers in the Bibliography; see Appendix.

The general outline of the diversion problem was discussed by Inglis (3). He indicated that in order to exclude heavy bed silt from intakes, one can either use a special still bond where the silt is deposited then scoured through undersluices, or one can properly design the intake. He recommended the use of bends in the main canal, supplying the intake from their concave side, i.e., outside (Fig. 2). The same results are given by Schoklitsch (4). Fig. 3 shows a good still bond.

Some engineers used inverted intakes (from the concave side of a bend) basing their idea upon the difference between the specific gravity of water and that of the suspended matter. They did not take into consideration the effect of the secondary current which will overbalance the effect of densities. Mr. Abdel Azim Ismail (5) advised the use of sand screens at intake. The sand screen is a small submerged wall across the canal bed of a height less than one third of the canal depth. He determined the dimensions of the screen from the study of sand concentration in canals which had no screens, without taking in consideration the effect of the existence of the screen in the canal. The screens are probably helpful in preventing the bed load from entering the branch canal, but they still require more study.

The study of the different field and model observations indicates that the flow of sediment in intakes is affected mainly by the three factors:

1) The difference between the density of water and that of sand.
2) The secondary currents.
3) The separation zones.

Difference of Densities:

According to the momentum theory, if the same lateral differential pressure is applied to different masses, the lighter will be more ready to change its direction.

$$F = \frac{d}{dt}(m\ v) = \rho Q\ (V_1 - V_2)$$

For the same force F and discharge Q, the smaller the density ρ the bigger is the change in velocities.

This phenomena was studied carefully in case of sampling in Reprt No. 5, St. Paul U.S. Engineer District (6). Curves were drawn between the variation in concentration and the ratio of velocities (Fig. 4). Two curves are given, one for sand diameter of 0.45 mm. and the other for 0.06 mm. sand. While the difference in concentration for first reaches 100% for a velocity ratio of 0.25, the error is 7% for the second. This indicates clearly the importance of sediment size in case of suspension. The results can be applied directly in case of an intake with a divide wall (Fig. 5). The load entering the branch will be a direct function of the velocity ratio. It will decrease if the branch velocity is relatively high.

Secondary Currents:

Secondary currents were well studied by Mackmore (7) and Shukri (8) in their work on bends. Mackmore observed and explained the existence of spiral motion in bends. It is caused by both the transverse distribution of pressure due to the centrifugal force around the bend, and the effect of boundary resistance on the velocity distribution. The net difference in pressure at different levels is the same and = $\Delta\rho$ (Fig. 6). This force is balanced by the centrifugal force, $m\ v^2/r$. Hence:

$$\Delta\rho = m\ v^2/r$$

Because velocity, v, at the bottom is lower than that at surface, the radius of curvature, r, will be high at surface and low at bottom. This variation in the curvature of the stream lines will cause a secondary or spiral motion of the flow. The higher the roughness of the boundary, the stronger will be the spiral motion.

Shukri showed clearly by direct measurements the existence of the spiral and succeeded in estimating its strength, Sxy. He obtained the expression $Sxy = \frac{(V^2xy/2g)m}{(U^2/2g)m} \times 100$ where $\frac{(V^2xy)}{2g}$ m is the mean head of velocity in plane x y normal to the direction of flow, and $\frac{(U^2)}{(2g)}$ m is the mean head of the resultant velocity. In his experiments the spiral strength, Sxy, reached 9% for high Reynolds number, Rn, and 2% for low Rn.

His velocity measurements proved that the free vortex assumption was true only at the cross section where the surface had maximum depression. He recommended the use of bends with the ratio rc/b of at least = 3.0 to get minimum secondary motion and no separation. r_c = radius of curvature of the centre line of the bend and b = width of the bend.

No measurements were taken for diversion of channels to show the secondary motion.

Lindner (9) believed, without proof, that near the canal bottom the component of velocity in the main direction is relatively low while it is high in the direction of the diverted channel. This was found to be true in the present measurements which show clearly the similarity of secondary currents in bends and in branches.

The importance of the secondary current with respect to sediment transportation was noticed many years ago. Nemenyi (10) believed that the secondary currents are the main factor in carrying the suspended load even along straight channels. The secondary currents at intakes are very effective in deflecting the layers of flow near the bottom towards the branch. This phenomena is important in distributing the sediment because of the high concentration of sediment in these bottom layers. Gerard Matthes (11) stated that in a natural stream, helicoidal flow occurs in the bends of relatively deep and narrow sections but not in the wide and shallow channels typical of big streams.

A diversion channel with a partial divide wall (Fig. 7) will combine the effect of density difference and of secondary currents. A properly designed divide wall should allow control of the sediment ratio in the two canals.

Separation:

The measurements of both Mackmore and Shukri show the separation zones existing at the inner side of the bend. Its position depends on the ratio rc/b and Rn, disappearing at rc/b = 3.00.

If the ratio of the radius of curvature to the channel width is low the rapid deceleration of the flow will produce the region of separation near the inside of the bend.

At intakes Leo Odom (12) observed that just inside the branching channel a roller or eddy was formed. This roller varied in intensity with the angle of diversion. A rounded corner at the convex side of the branch canal entrance tended to decrease the roller allowing more water but less sediment to enter the branch.

Sediment Distribution at Diversion:

Most of observations on diversion in the field describe the sediment motion. The size of sand used as sediment has a great effect on its behaviour.

Extremely fine material has an extremely small settling velocity. It has veglegible resistance to the turbulence of flow and hence moves homogeneously in suspension with the water. Its concentration is nearly uniform all across the stream. In a diversion such fine material will move with same ratio as the water. This was proved experimentally by Herbert Vogal (9).

Coarser material will move either in suspension or as bed load or interchanging from one to other. In all cases the lower layers have high concentration of such coarse material. Any increase or change in direction of the velocity of lower layers will appreciably affect the sediment distribution. The secondary currents at a diversion deflect the lower layers causing high concentration of coarse material to enter the branch. Linder and Vogal (9) proved this experimentally. H. Einstein has demonstrated this phenomena by using the simple diversion take-off shown in (Fig. 8). The quantity of diverted sediments will be reduced only when the flow is directed by a deflector towards the branch (Fig. 8b).

Objective of Study

The previous discussion showed the numerous variables included in the diversion problem. Many workers have shown that the sediment load is a function of the flow, and have shown the general nature of the relationship. The complexity of the problem has dictated that the present study consider only the flow problem.

It is true that the existence of sand will alter the flow characteristics but the difference is too small to change the main pattern of the problem.

It is suggested that a series of tests be made studying the effect of sand screens and changes of bed levels at canal diversion. Another series of tests can be made by adding sand of different sizes to the water in a special closed circuit flume.

Apparatus and Procedure

A wooden flume 100 cms wide and 400 cms long was used for conducting the experiments (Fig. 9). It was divided into a main canal of 50 cms wide and a space where the subsidiary canal was constructed. The inlet and the subsidiary canal were built out of small steel T sections which was a flexible method for constructing channels of different sizes and shapes.

A small current meter with a runner of 1/2 inch diameter, which was made according to Mr. Black's design (13), was used to measure the total resultant velocity at different points. The current meter cannot determine the direction of the flow.

Two readings were taken at each point on the plan, one at about 1.5 cm. below the water surface and the other at 1.0 cm. above the bed. The current meter was held in position by hand. The runner of the meter was so small that the torque causing its rotation could not overcome any external resistance like that caused by electrical contact. This fact did not allow the use of electric speed recording and the number of turns was counted by eye. This limited the use of the current meter to velocities less than about 24 cm/sec. which corresponds to 150 R.P.M. Turns corresponding to speeds higher than that could not be counted by eye. On the other hand, the friction at the bearings limited the minimum velocity to 5 cm/sed. Velocities less than that could not rotate the meter.

Two measuring tanks were used for getting both the discharges through the

main and branch canal. Normal scales were used to measure the depth of water.

Twelve runs were carried out during this series. The width of the main canal was kept constant and equal 50 cm. The first four runs had a branch canal width = 15 cm. and an angle of twist of 90°. The ratio between mean velocity in the main and that in the branch was changed from run to another by changing the heights of the weirs placed on both exists of canals. In Runs 5 and 6 the branch canal had a width = 10 cm and same angle of twist 90°. Runs 7 and 8 had a canal width = 9 cm and an angle of twist = 108°. This angle corresponds to a slope of 3:1 from the line of 90°. Runs 9 and 10 had a canal width = 8.5 cm. and an angle of twist of 72°. Runs 11 and 12 had a canal width = 13.5 cm. and an angle of 72°.

The size of the branch canal was limited by the total width of the flume. A canal wider than 15 cm. would require bigger area than the available or else the effect of the bend, which followed the inlet, would interfere with the flow conditions at the inlet.

Results

Fig. 10 to 13 plot the data measured in four of the twelve runs. The two measured values of the velocities are written at the corresponding point. That near the surface is written above that near the bed. Velocity profiles and velocity contours are plotted for different sections. Separation zones are indicated as given by direct observation of injected dye and verified by velocity measurements. The results obtained from all the experiments are collected and summarized in Table 1.

The channels were rectangular and of sharp edge at the meeting point. This results in all the runs a clear zone of separation. When the current meter was placed in such a region, it did not rotate showing an average velocity of zero, or more precisely an average velocity less than 5 cm/sec. A separation zone in a channel means a dead part which reduces its efficiency. If such zones are not eliminated by proper design, the deposit of the sediment will accumulate there and modify the section to be free from separation. A properly designed passage will smoothly deflect the flow in the require direction. In order to reach such a design the passage of the dye injected at the meeting point of the channels was carefully studied. The observed shape of an ellipse remind the writer of the elliptic inlets suggested by Hassan and Rouse (14) for cavitation free inlets. It was found that a quarter of an ellipse fit the curves given for the separation zone. These ellipses were represented by half the major and minor axes divided by the net effective width of branch canal, $\frac{\alpha}{b'}$ and $\frac{\beta}{b'}$ (Fig. 10). It is also possible to represent the ellipse by the single value of its radius of curvature at the meeting point r. It is believed that this value is the main factor affecting the existence of separation zone.

The general term for the radius of curvature is

$$r = \frac{(1 + y'^2)^{3/2}}{y''}$$

In case of ellipse

$$r = \beta^2/\alpha \text{ at the end of the major axis.}$$

The values of r/b' are given in Table 1.

As for secondary flow, Shukri's method was used to evaluate the spiral strength

$$Sxy = \frac{(V^2xy/2g)m}{(U^2/2g)m} \times 100$$

The total resultant velocity U was measured directly with the current meter. The discharge divided by the area of flow gave the velocity of flow V in the direction of the channel axis.

$$V^2xy = U^2 - V^2$$

$$Sxy = \frac{U^2 - V^2}{U^2} \times 100$$

These values are given in Table 1.

The variables studied in the present work were: For the channel shape, the ratio of canal size and the angle of twist. For the flow characters, the magnitude of the velocities in both canals. The study of the results proved that the main factor affecting the flow was the ratio between the velocity of the main canal to that of the branch V_m/Vb. It was possible to draw a smooth curve (Fig. 15) between r/b' and Vm/Vb and another curve (Fig. 14) between Sxy and Vm/Vb. It is clear from both curves that r/b' and Sxy are direct functions of the variable Vm/Vb. Both increase with the velocity ratio.

CONCLUSIONS

1) The velocity ratio Vm/Vb is the main independent variable in case of canal diversion.
2) Separation zones at intakes can be represented by r/b'. The larger the value of r/b' the smaller the separation will be and the smoother will be the flow. A separation free intake may be accomplished by having a quarter of an ellipse at the intake. α/β of such an ellipse can be approximated by 2.5, but the actual value is a function of Vm/Vb and can be evaluated from Fig. 15.
3) The strength of spiral motion is a direct function of Vm/Vb. For high Vm/Vb, Sxy will be high and a larger quantity of sediment will enter the branch.
4) The variation of Rn and F was so limited that no definite relation could be derived.
5) The relative width and the angle of twist had no appreciable effect on the values of r/b' and Sxy.
6) The smallest possible Vm/Vb is recommended for diversion operation to get minimum separation and minimum secondary currents.
7) This field is still widely open for future study. It is believed that the study of intake with partial divide wall will lead to a good solution for this problem.

APPENDIX I

NOTATION

The following letter symbols, introduced in this paper, are assembled here after:

All letters with annex b refer to the branch canal

All letters with annex m refer to the main canal

- a - a length representing the test
- b - canal width
- b' - effective width of branch canal
- c - concentration of sediment
- c_o - concentration of sediment at bed
- d - water depth
- e - absolute roughness of bed
- F - Froud's Number
- G - total load of sediment
- p - intensity of pressure
- Q - discharge
- r - radius of curvature
- r_c - radius of curvature of centre line
- S - spiral strength
- t - duration of test
- V - mean velocity
- W_m - mean settling velocity
- α - half major axes of ellipse
- β - half minor axes of ellipse
- ρ - density
- θ - angle between the two canals
- σ_w - geometric standard deviation of W_m

APPENDIX II

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Table No. 1

Run No	Width b_b cms	Angle of twist θ	Depth d_m cms.	Depth d_b cms	Veloc. V_m cm/sec	Veloc. V_b cm/sec	$\frac{V_m}{V_b}$	U_b cm/sec	Effective width cms	$\frac{\alpha}{b'}$	$\frac{\beta}{b'}$	$\frac{\alpha}{\beta}$	r/b'	S_b %	$F_b = V/\sqrt{gd}$
1	15	90	5.9	5.4	9	15.4	0.58	18.3	10.3	1.1	0.46	2.4	0.19	29	0.21
2	15	90	4.5	3.9	13.2	15.9	0.83	20	10.4	1.3	0.44	2.9	0.15	37	0.256
3	15	90	3.7	3.2	16.8	11.6	1.45	18.6	8.3	1.7	0.8	2.2	0.37	60	0.207
4	15	90	4.5	4.2	15	8.3	1.8	14.2	7.5	1.9	1.0	1.9	0.53	65	0.13
5	10	90	4.6	4.4	8	13.4	0.6	17.4	8.0	1.1	0.25	4.0	0.06	40	0.204
6	10	90	4.0	3.8	15.2	8.6	1.77	15.5	6.1	1.3	0.65	2.0	0.33	68	0.14
7	9	108	5.2	5.0	7.7	13.0	0.6	16.0	6.8	0.8	0.33	2.4	0.14	33	0.185
8	9	108	4.2	4.0	15.0	7.8	1.92	15	6.5	0.8	0.40	2.0	0.40	73	0.125
9	8.5	72	4.5	4.4	8.5	16.3	0.52	19	7.1	0.5	0.2	2.5	0.08	27	0.25
10	8.5	72	4.1	4.0	16.1	10.6	1.52	20	5.3	1.5	0.6	2.5	0.24	70	0.17
11	13.5	72	4.6	4.5	7.4	10.0	0.74	10.4	10.0	1.1	0.3	3.3	0.08	8	0.15
12	13.5	72	4.1	3.9	15.6	7.0	2.22	16.0	5.3	2.0	1.2	1.7	0.72	80	0.115

m : for main canal V : Vel. of flow along the axis of channel α & β = major and minor axis of ellipse

b : for branch canal U : total resultant velocity r = radius of curvature at entrance

b': effective width of branch channel S : strength of vertex at branch

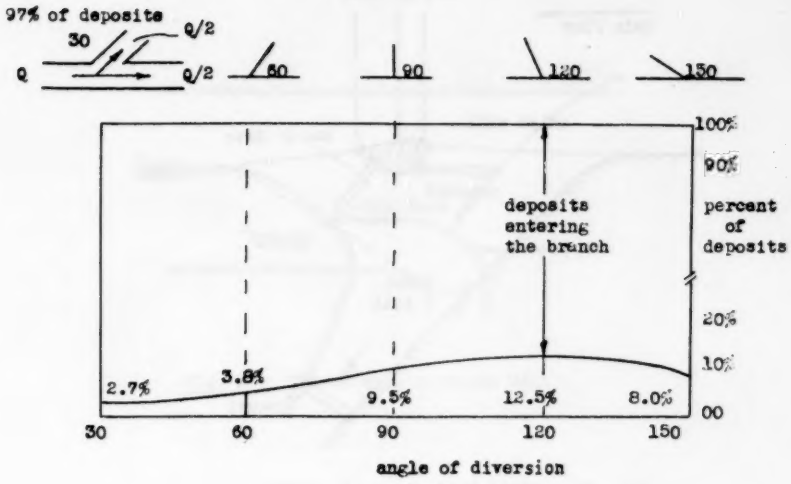


Fig. 1 : Effect of ancle of twist on the diversion of sediment

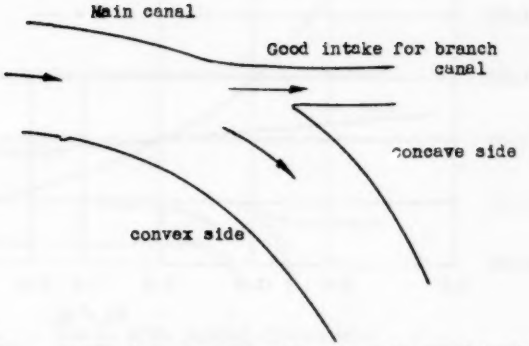


Fig. 2 : Intake from concave side of a main canal bend.

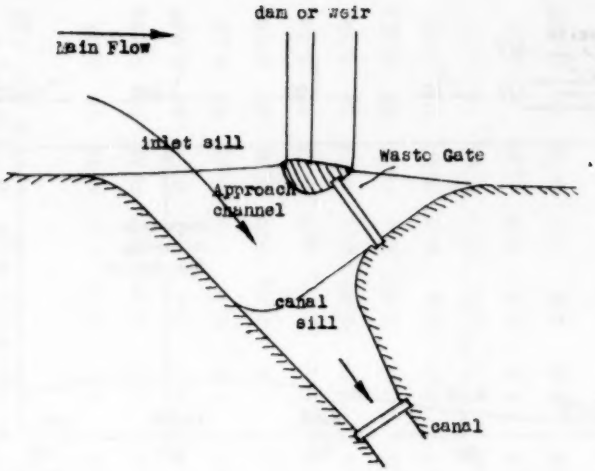


Fig. 3 : Still bond at canal intake.

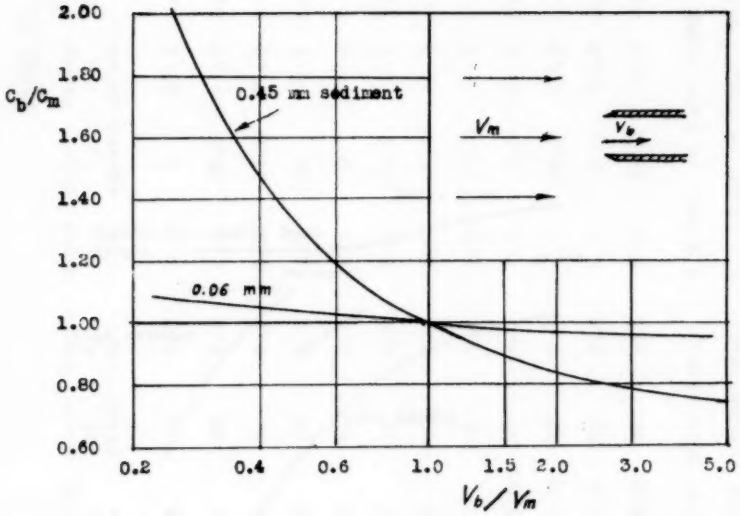


Fig. 4 : Effect of relative velocity on relative concentration

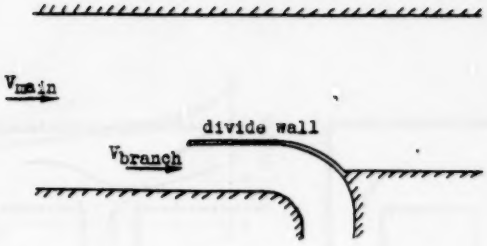


Fig. 5 : INTAKE with a Divide Wall

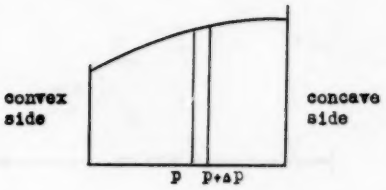


Fig. 6 : Effect of Centrifugal force on pressure at a bend

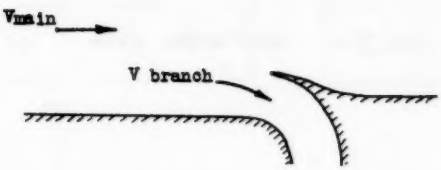


Fig. 7 : Intake with partial divide wall

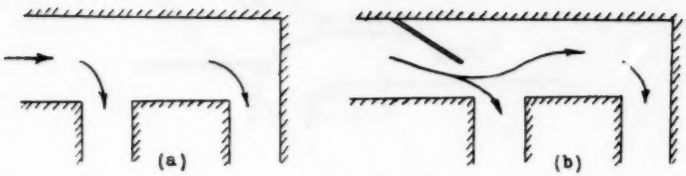


Fig. 8 : Einestein demonstration of sediment diversion

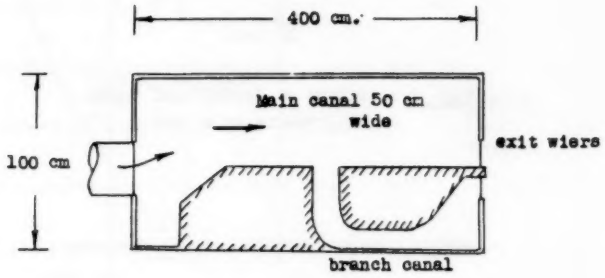


Fig. 9 : Experimental flume

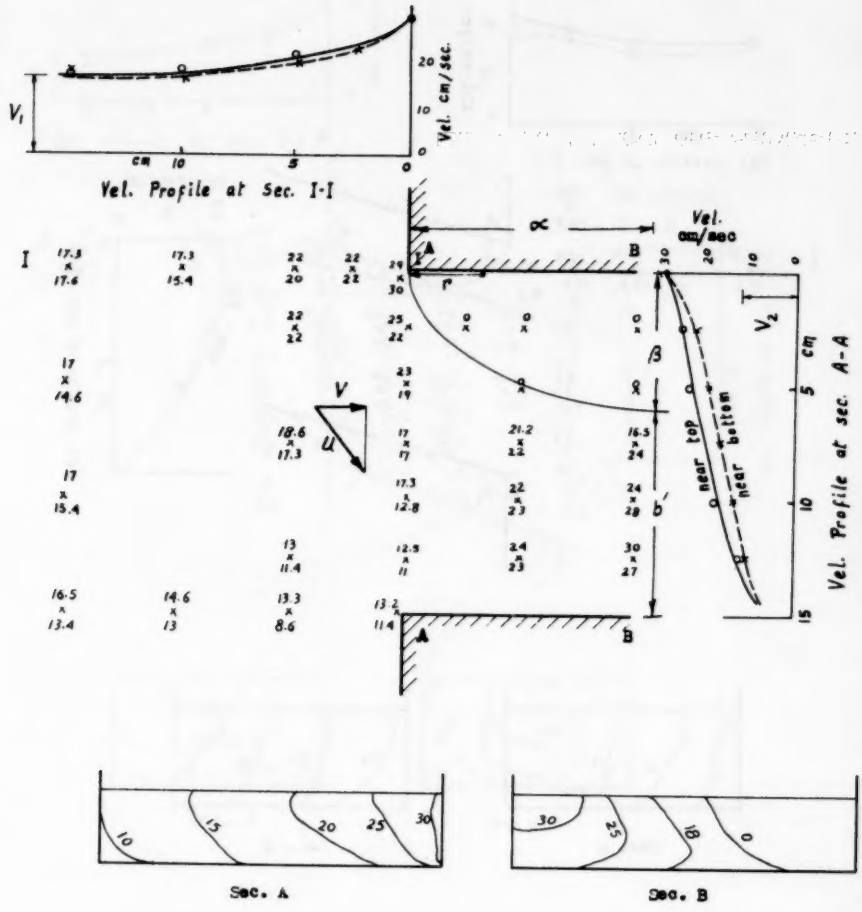


Fig. 10 : Run No. V_m V_b d_m d_b U_b b' S_b

3 16.8 11.6 3.7 3.2 18.6 8.3 60%

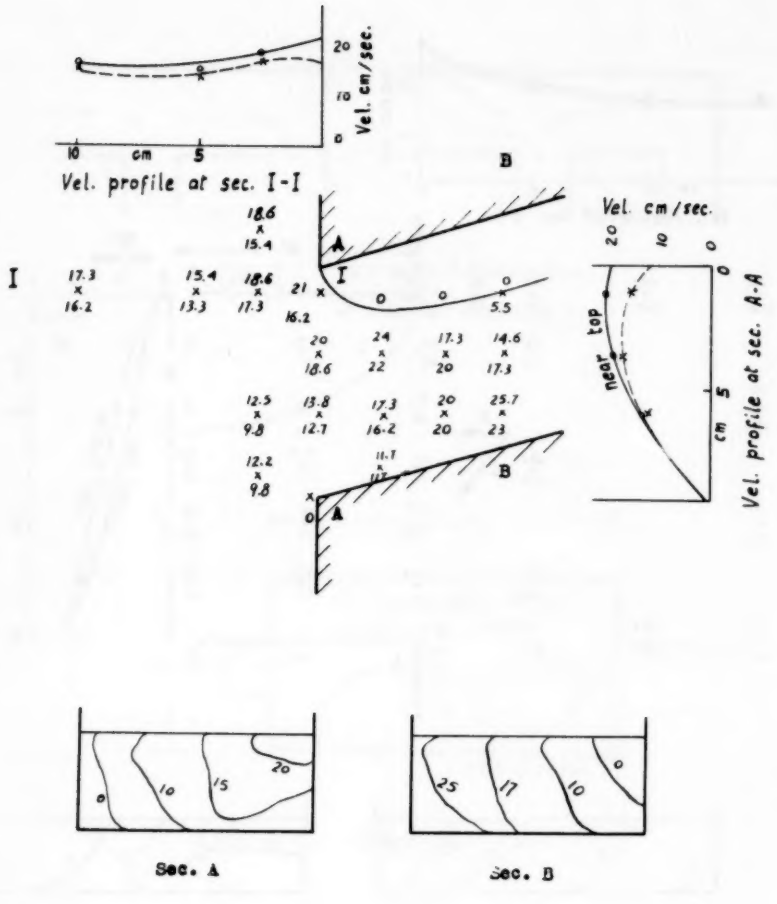
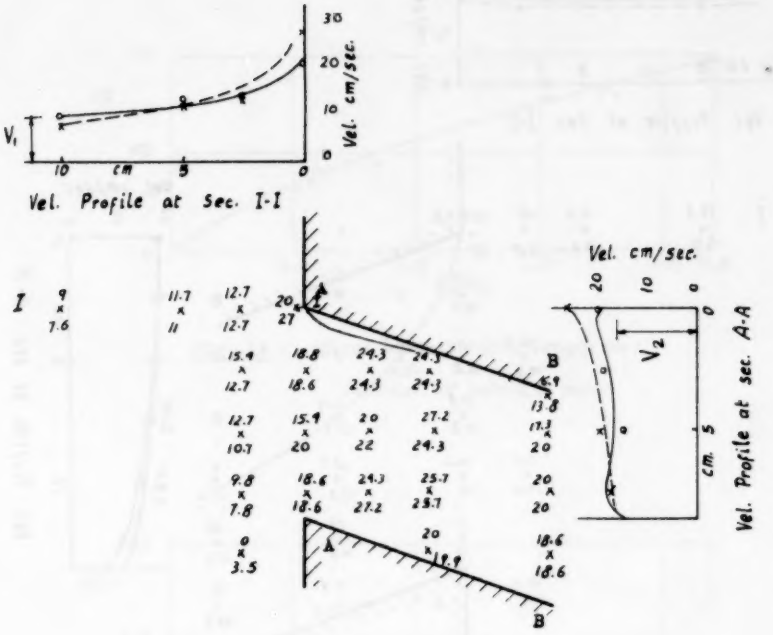
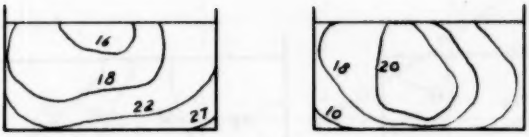


Fig. 11 :

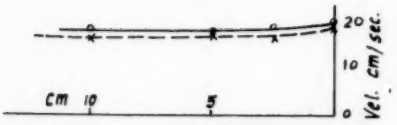
Run No	V_m	V_b	d_m	d_b	U_b	b'	S_b
8	15.0	7.8	4.2	4.0	15.0	6.5	73%



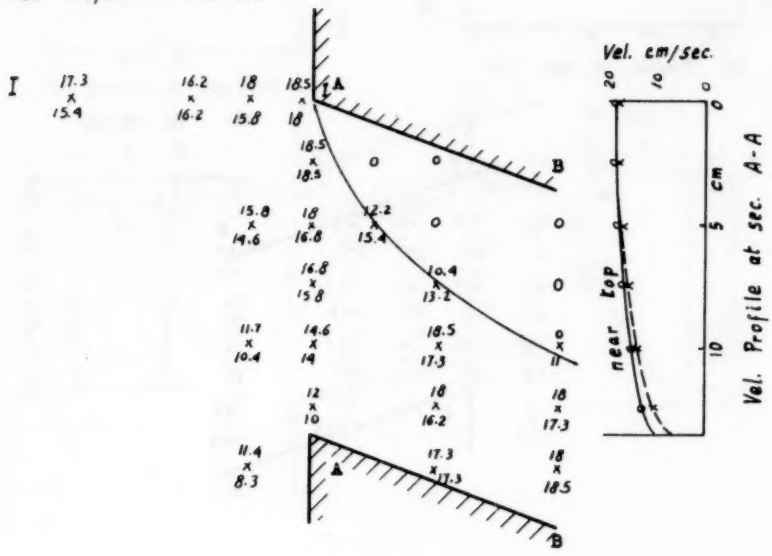


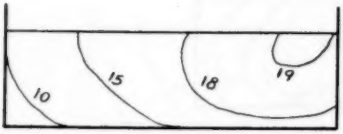
Sec. A Sec B

Fig. 12 :	Run No	V_m	V_b	d_m	d_b	U_b	b'	S_b
	9	8.5	16.3	4.5	4.4	19.0	7.1	27%

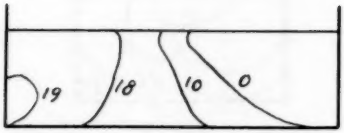


Vel. Profile at Sec. I-I





Sec. A



Sec. B

Fig. 13 :

Run No	V_m	V_b	d_m	d_b	U_b	b'	S_b
12	15.6	7.0	4.1	3.9	16.0	5.3	80%

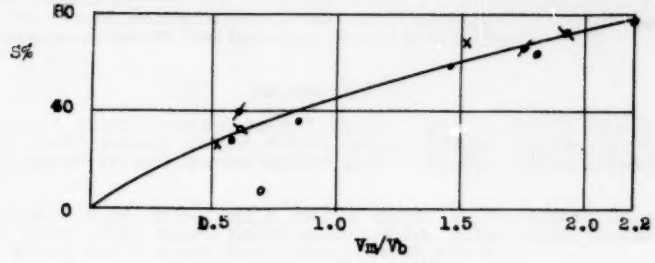


Fig. 14 : Spiral strength in a branch as a function of velocity ratio

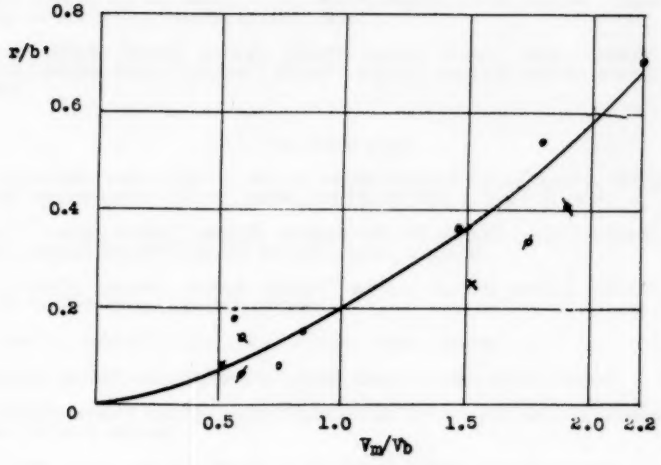


Fig 15 : Radius of curvature r against the velocity ratio V_m/V_b

PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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a. Beginning with "Proceedings-Separate No. 200," published in July, 1953, the papers were printed by the photo-offset method.
b. Presented at the Miami Beach (Fla.) Convention of the Society in June, 1953.
c. Presented at the New York (N.Y.) Convention of the Society in October, 1953.
d. Beginning with "Proceedings-Separate No. 290," published in October, 1953, an automatic distribution of papers was inaugurated, as outlined in "Civil Engineering," June, 1953, page 66.
e. Discussion of several papers, grouped by divisions.
f. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
g. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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